

On the excess of power in high resolution CMB experiments

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Abstract. We revisit the possibility that an excess in the CMB power spectrum at small angular scales (CBI, ACBAR) can be due to galaxy clusters (or compact sources in general). We perform a Gaussian analysis of ACBAR-like simulated data based on wavelets. We show how models with a significant excess should show a clear non-Gaussian signal in the wavelet space. In particular, a value of the normalization $\sigma_8 = 1$ would imply a highly significant skewness and kurtosis in the wavelet coefficients at scales around 3 arcmin. Models with a more moderate excess also show a non-Gaussian signal in the simulated data. We conclude that current data (ACBAR) should show this signature if the excess is to be due to the SZ effect. Otherwise, the reason for that excess should be explained by some systematic effect. The significance of the non-Gaussian signal depends on the cluster model but it grows with the surveyed area. Non-Gaussianity test performed on incoming data sets should reveal the presence of a cluster population even for models with moderate-low σ_8 's.

Key words. cosmological parameters, galaxies:clusters:general

1. Introduction

In the last couple of years there have been several results suggesting that there is a significant excess in the power spectrum of CMB experiments at small scales ($\theta < 5$ arcmin or $\ell > 2000$) (CBI, Pearson et al. 2003; ACBAR, Kuo et al. 2002). The best candidate for this excess (if confirmed) is the SZ effect signal in galaxy clusters. We expect the excess in power due to galaxy clusters to be observed at some point at scales smaller than \approx few arcmin (or $\ell > 3000$) although the exact value is model dependent. However, the amplitude of the excess claimed by recent experiments is larger than what it is expected for the current most fashionable models. In fact, if that excess is confirmed to be due to galaxy clusters, it would require high values for the normalization of the matter power spectrum ($\sigma_8 \approx 1$) (e.g Bond et al. 2002). These high values of σ_8 would contradict the values derived directly from observations of galaxy clusters (e.g Efstathiou et al 2002). Another contribution to the excess in power could be due to unresolved non-subtracted point sources. It is expected to be more important for experiments at low frequencies in the microwave band (like CBI) than at frequencies around 150 GHz (like ACBAR). Since a strong contribution from radio sources is expected in the former case and in the latter the extragalactic point source contribution is at the lowest level along the microwave band, a more significant residual after the subtraction/estimation analysis can be present at centimeter rather than millimeter wavelengths. Moreover, the effect of clustering of point sources should be considered in the estimation of the residual (Toffolatti et al. in preparation).

An interesting aspect of the excess in power is that no compact sources (clusters or point sources) are clearly seen directly in the data, thus suggesting that the origin of this excess may be due to a different nature other than the compact sources. One has only to realize that the power spectrum is an averaged quantity over the surveyed area and that the compact (bright) sources are not distributed over the whole area. As a consequence, many pixels will enter in the average with negligible values. On the other hand, the CMB does distribute over the whole surveyed area. This implies that if the power spectrum of compact sources dominates the power spectrum of the CMB at small scales, then those sources should be seen in the map at small scales. Then, where are they? The debate is still open and it is not clear whether the excess is due to compact sources or is just a systematic effect.

In this paper we will study the SZ contribution to the excess found in the power spectrum and its cosmological implications.

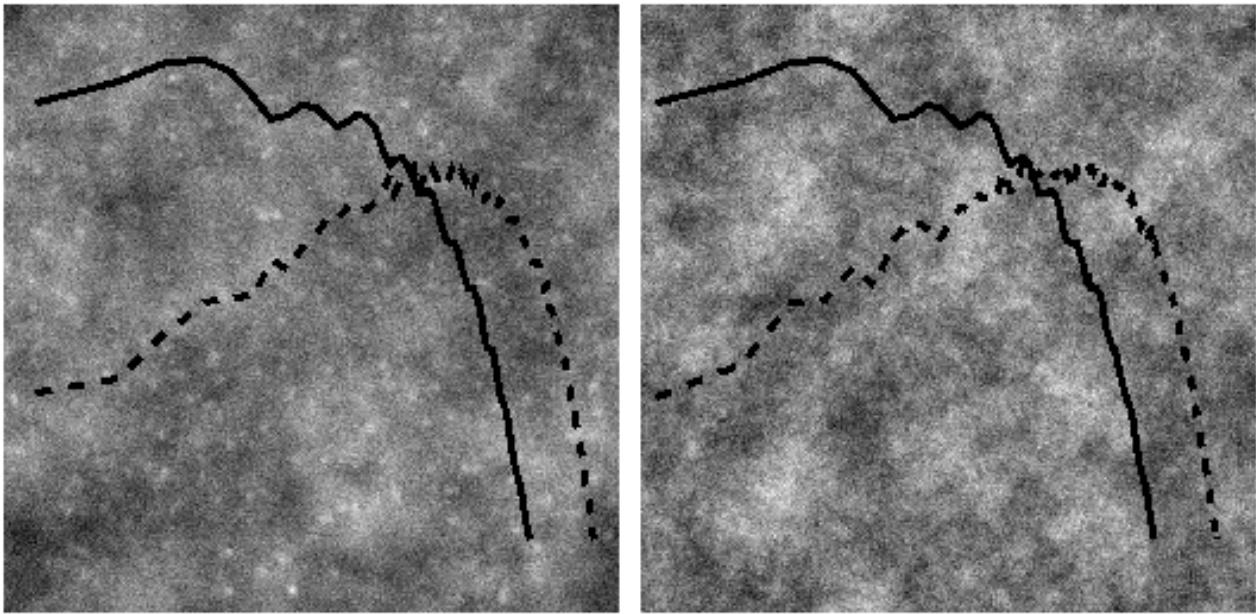


Fig. 1. The power spectrum of the CMB realization and the point sources (convolved) is shown as solid and dashed lines respectively. The population of sources consist of 1000 point sources distributed in 1.5 % of the total number of pixels and with random (uniform) amplitudes between 0 and 1×10^{-3} K (left) and 30000 point sources (in 40 % of the total number of pixels) with random amplitudes (uniform) between 0 and 2.5×10^{-4} K (right). The point where both powers cross is at about $\ell \approx 2000$. Each image is 6×6 sq. deg.

In particular we will analyze the Gaussian deviations introduced in the wavelet coefficients. Since the CMB has not shown (up to date) any departures from Gaussianity at least at those small scales (for larger scales see Vielva et al. 2003) therefore any non-Gaussian detection would point out the presence of compact sources.

The analysis presented in this paper will be useful to confirm or reject the hypothesis that the excess is due to galaxy clusters in current CMB data. The analysis would be also a desirable consistency check with the near future incoming data sets. The reader will find very interesting for instance the pioneering work of Aghanim & Forni (1999) and the more recent of Rubiño-Martin & Sunyaev (2003) where similar questions are considered.

2. Searching for compact sources signatures

Our aim is to show how it should be possible to reject the possibility that the excess is due to galaxy clusters or to confirm that the excess in power is due to a signal which is compact. The main idea follows the argument in the introduction, *if the power spectrum at small scales is dominated by compact (non-Gaussian) sources, then these compact sources should produce a non-Gaussian signal at small scales.*

We illustrate this point with figure 1 (left) where we simulate a realization of the CMB (with a standard WMAP-like power spectrum, Hinshaw et al. 2003) and we add a population of point sources (we also add instrumental noise with an rms of $30 \mu\text{K}$ per pixel). The population of sources consist of 1000 point sources (convolved with an antenna beam of 5 arcmin) with amplitudes ranging from 0 to 0.001 K (uniformly distributed in that range). In the same plot we also show the power spectrum of both the antenna-convolved CMB and the convolved point sources. At $\ell \approx 2000$ the power spectrum of the point sources starts to dominate the power spectrum of the CMB. Many point sources can also be seen very clearly in the map even without any filtering. There is however other situation in which an excess in the power due to compact sources does not mean one actually has to see the sources in the map clearly. An excess in power can be due to the presence of relatively few bright sources (this is the case of figure 1) or it can be due to the presence of a large number of weak, almost undetectable compact sources. The later case is shown in figure 1 (right). In this case we take 30000 point sources (instead of the 1000 point sources of figure 1 left) but we lower the maximum amplitude down to 2.5×10^{-4} K. This second case could explain why the experiments claiming the excess in power have not found the sources of this excess. However, in both cases, if the excess is due to compact sources, their signal must be detectable not only in the frequency domain (power spectrum) but also in the real space domain (at the scales where they dominate the power). A good way of looking for signatures of the compact sources in real space is by looking at the Gaussian properties of the data. Since compact sources are known to be very non-Gaussian signals, they should leave a non-Gaussian imprint in the data. The problem is that if one looks directly at the Gaussian properties of the data, the statistics may be easily dominated by the properties (Gaussian) of the CMB and the noise. This will be particularly true in our case where we may

expect a small fraction of the total number of pixels to be affected by the non-Gaussian compact sources. A better approach is to pre-process the data somehow to increase the signal-to-noise ratio of the non-Gaussian compact sources with respect to the Gaussian CMB and noise. This later point can be achieved by doing an appropriate filtering of the maps. When we look at the Gaussian features of our toy model in figure 1, we find that after a proper filtering they show non-Gaussian signatures which correspond to the presence of the compact sources. For instance, looking at the skewness with the MHW (Mexican Hat Wavelet) at scales of 1.5 pixels there is a non-Gaussian signal at 40σ significance in the first case (fig. 1 left) and at 5σ significance in the second case (fig 1 right). The significance is calculated from a set of 500 simulations with the same CMB power spectrum and noise as in the cases of figure 1.

There are a variety of filters which can make the job. In this work we will use the MHW (Cayón et al. 2000 and Vielva et al. 2001) although the reader is free to consider other (maybe more effective) filters (Sanz et al. 2001 and Herranz et al. 2002).

To quantify the contribution of the non-Gaussian compact sources we will use non-Gaussianity estimators like the skewness and kurtosis and we will apply these estimators to the wavelet-filtered data. We expect the signal from clusters to dominate the CMB signal only at small scales. Going to the wavelet space (or filtering with an appropriate filter) is important to select the scales of interest. Since the data is not available we will use simulations which reproduce the data to the best of our knowledge.

3. Simulations

We will try to emulate the ACBAR data, in particular we simulate the deepest section of the CMB5 field. It covers an area of the sky of about 3 square degrees with an almost homogeneous noise level over the field of $8 \mu\text{K}$ per resolution element. We will include also the effect of the antenna beam by convolving our simulations with a 5 arcmin FWHM Gaussian beam.

The ingredients of the simulation will be the CMB component with a power spectrum which matches the WMAP power spectrum (Hinshaw et al. 2003), the noise level assuming it is white-Gaussian and with the above level, and a population of compact sources (clusters) with a power spectrum which is consistent with the excess in power suggested by the ACBAR and CBI teams.

The galaxy cluster population is model dependent. We will assume two models which are marginally consistent with the measured power spectrum by ACBAR and CBI. In this paper we do not pretend to make a detailed study of the models which can explain the excess. We will show however how models predicting an excess in the range of the observed one should also produce non-Gaussian signals at small scales. A more detailed modeling would be required however, if a serious analysis of the real data is performed. Unfortunately, the data is not freely available. Nevertheless, our two simple models should suffice to describe the range of possible models explaining the excess.

We will call model A (or $\sigma_8 = 1.0$) the one with a significant excess and marginally consistent with the upper limit ($\approx 2\sigma$) of the data error bars. Model B (or $\sigma_8 = 0.8$) is marginally consistent ($\approx 2\sigma$) with the lower limit of the error bars. For modeling the clusters we will use Press & Schechter (1974) and a parametrization of the temperature-mass and the virial radius-mass relations following Diego et al. (2001). We also assume a β -model for the electron density ($\beta = 2/3$). The details of the model are not particularly relevant as long as their power spectrum is consistent with the excess. The parameters of the models are described in table 1. There is an extra-parameter not listed in the table which controls the ratio $p = R_v/R_c$ which we fix to $p = 10$ (R_v and R_c are the virial and core radius respectively). In both cases, we assume a ΛCDM flat universe with $\Lambda = 0.7$. The power spectrum of the two models is shown in figure 2. The difference in the cosmological parameters between the two models is just the normalization parameter σ_8 . We also have changed the temperature normalization which boost the power in model A by a factor $(9/8)^2$ with respect to model B. Changing the rest of the parameters can also change the power (specially at small scales). For our purposes, models A and B are sufficient since they represent the upper and lower limits respectively given by the data.

4. Results

With the above models, we make 500 simulations of the CMB plus noise and 500 simulations for each of the two models (Model A with $\sigma_8 = 1$, and model B with $\sigma_8 = 0.8$). With these simulations we build 3 kinds of maps, i) CMB + Noise, ii) CMB + Noise + Model A, and iii) CMB + Noise + Model B. The first set of maps is necessary to establish the significance of any possible non-Gaussian detection. With the second and third sets of maps we will test the sensitivity of the skewness and kurtosis of the filtered maps to the non-Gaussian signatures due to the clusters. We use the MHW to select different scales in the simulated maps and to amplify the non-Gaussian signals with respect to the Gaussian ones (CMB and noise). Then we look at the skewness and kurtosis of the wavelet-filtered maps as a function of the scale. Eventually, for a range of scales we can see the non-Gaussian features of models A and B and there will be an optimal scale for which these features are seen most clearly. In figures 3 and 4 we show the skewness and kurtosis for the two corresponding optimal scales. The most remarkable thing from these results is that for models having a high power at small scales (like Model A), we should expect to see a significant non-Gaussian signature in maps like the ACBAR ones.

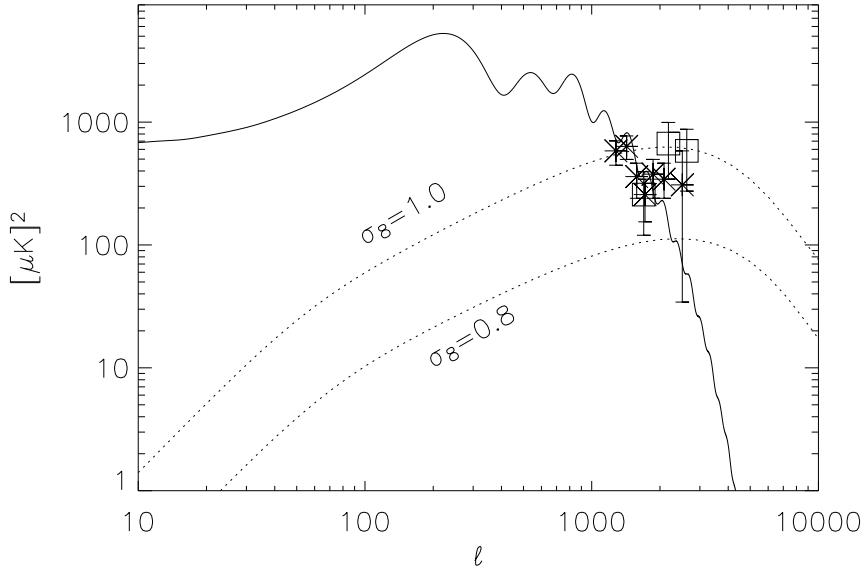


Fig. 2. Power spectrum of the CMB used to simulate the data (solid line) compared with the power spectrum of the two models used to simulate the clusters (dotted lines). Also shown is the ACBAR (stars) and CBI (squares) data showing the excess in power at high ℓ 's

	Ω_m	σ_8	T_o	α	ϕ	R_o	ψ
A	0.3	1.0	9.0	0.55	1.0	1.5	-1
B	0.3	0.8	8.0	0.55	1.0	1.5	-1

Table 1. Parameters taken in models A and B. The temperature-mass relation is given by $T = T_o M_{15}^\alpha (1+z)^\phi$ and the virial radius-mass relation is given by $R_v = R_o M_{15}^{1/3} (1+z)^\psi$. All numbers are dimensionless except T_o (Kev) and R_o (h^{-1} Mpc)

Even for models with a relatively low power (model B) we could expect to see non-Gaussian features in an appreciable fraction of the realizations.

At this point, it is important to note that the dispersion of the distributions shown in figures 3 and 4 decreases as the surveyed area increases. This means, that a larger area of the sky would reduce the overlapping area between the distributions of model B and the Gaussian case, thus allowing a detection of the non-Gaussianity induced by clusters even for these models.

5. Discussion

We have presented a small (but interesting) excercise showing how current data (ACBAR CMB5 field) is expected to have non-Gaussian signals if the claimed excess in the power spectrum is fully due to the SZ effect. With this excercise we want to send a brief but clear note to the community. Current data should be checked for non-Gaussian signals at small scales before any excess in the power spectrum is claimed as due to the SZ effect.

The potentiality of this approach is based on the fact that, up to date, no intrinsic deviations from Gaussianity have been found in the CMB at these small scales. Any deviations would indicate the presence of compact sources which are expected to be the dominant foreground at arcmin scales.

We have presented the result of the level of non-Gaussianity we should expect in ACBAR-like data if a significant excess in power is due to galaxy clusters. Given the uncertainties in the estimation of the power spectrum by ACBAR and CBI, we explore two models which are in the lower and upper limit of these uncertainties and we find that for the model in the upper limit we should expect a clear non-Gaussian signal at MHW scales around 3 arcmin (the Gaussian and A-model distributions in figures 3 and 4 overlap by less than 1 %). In the other case (lower limit B-model), we should expect a non-Gaussian signal in $\approx 75\%$ of the cases if we look at the kurtosis and in $\approx 80\%$ if we look at the skewness (both at $> 99\%$ confidence limit). By performing this analysis on the ACBAR data (for example), one could confirm or reject several galaxy cluster models.

Although we have based our simulations on galaxy clusters, a similar argument could be made if the excess is due to point sources. A way to distinguish between both would be the sign of the skewness of the MHW coefficients: a positive sign would

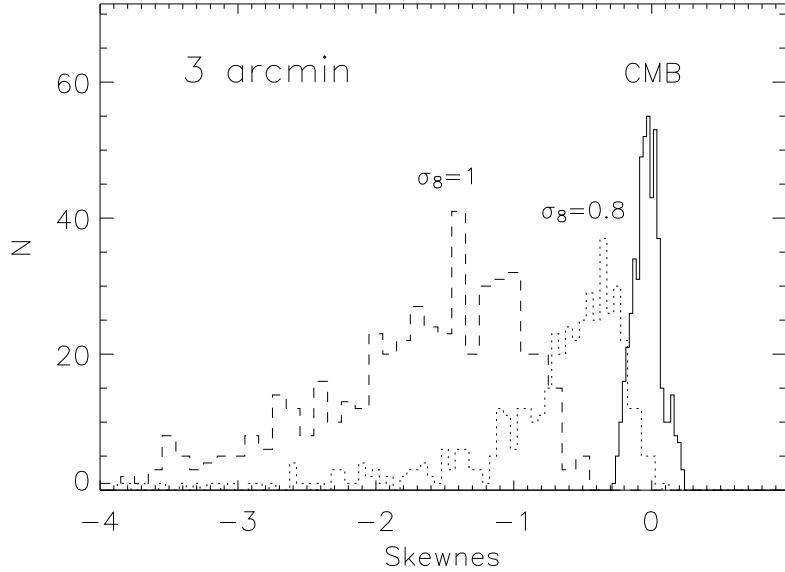


Fig. 3. Distribution of skewness of the simulated maps after filtering with a MHW of 3 arcmin scale.

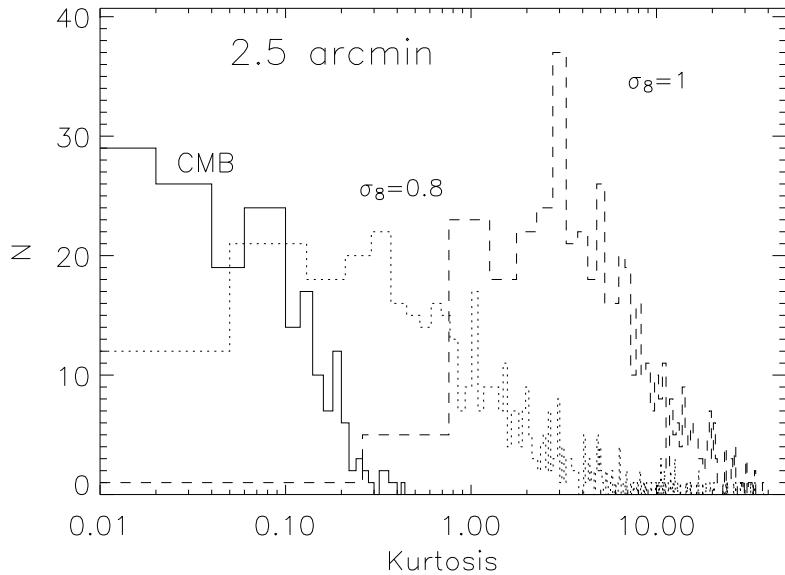


Fig. 4. Distribution of kurtosis of the filtered maps after filtering with a MHW of 2.5 arcmin scale.

point out to point sources whereas a negative one would imply the presence of galaxy clusters (see Rubiño-Martin & Sunyaev 2003). For experiments where the level of non-Gaussianity is expected to be small, a more efficient manner to discriminate between the CMB and galaxy clusters is by defining a Fisher discriminant which contains information about both the skewness and kurtosis and also at several scales (Martínez-González et al. 2002). These techniques will prove to be very useful with the near future data.

We would like to conclude by being provocative by insisting that actual data should be checked for non-Gaussian signals before suggesting that the excess is due to the SZ effect. If the data is found to be compatible with Gaussianity, then the systematics may be the reason for that excess. For instance, the power spectrum may have been overestimated at small scales if the covariance matrix of the instrumental noise is slightly undetermined at those small scales. Although we are not the first suggesting that non-Gaussianity studies are useful to detect SZ signatures (See Aghanim & Forni 1999 or Rubiño-Martin & Sunyaev 2003), we are the first in predicting that if a significant excess claimed by recent experiments is due to the SZ effect, in general, non-Gaussian

signals should be found with a high significance in at least one of those data sets, the CMB5 field of ACBAR. The reader may consider our approach too simplistic but we think is important to highlight our main point with simple arguments, current data should be checked for non-Gaussian signals.

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